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Original Articles

Riparian forest corridors: A prioritization analysis to the Landscape Sample Units of the Brazilian National Forest Inventory

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ABSTRACT

In addition to sampling biophysical data in field plots, the Brazilian National Forest Inventory (NFI-BR) has a component dedicated to the study of Brazilian rural landscapes. The Landscape Sample Units (LSUs) are square areas of 100 km^2, established in a regular grid of 40 × 40 km over the entire national territory, where habitat quality and spatial structure are characterized and evaluated. The LSUs' evaluation scheme measures the fragmentation and connectivity of remnant forest patches as well as the spatial configuration of riparian zones. As part of these analyses we propose the use of integrated indices based on the structural connectivity of the riparian environments as forest corridors, the degree of human pressure acting on them and the protection schemes defined by the new Brazilian forest legislation. These indices are then turned into scores to make a ranking allowing for the identification of riparian priority areas for conservation and landscape restoration. Basic processing steps included the application of Morphological Spatial Pattern Analysis (MSPA) to the LULC map of a pilot sample from the LSU dataset in the State of Paraná, in southern Brazil. The following indices have been calculated for 20 LSUs: Structural Corridors Index (SC_c), which reveals the proportion of *core* and *bridge* MSPA categories within the riparian zone, the Structural Corridors under Pressure Index (CP_c), that allows the identification of areas where structural corridors coexist with areas subject to anthropogenic influences and, finally, the Structural Corridors under Pressure Protection Index (UCP_c), which identifies areas that function as corridors, being under anthropogenic pressure as well but with little or no legal protection, thus corresponding to priority areas for conservation. Among the 20 pilot LSUs studied, three of them are representative of a critical situation regarding conservation issues as they presented high values for indices CPc and UCPc, which denote areas with high anthropogenic influences and no environmental protection schemes. An important aspect of the proposed methodology is the possibility to identify and prioritize areas at different spatial scales, further aggregating the indices for LSU or larger political regions, such as micro and mesoregions of federal states.

1. Introduction

Among the many existing definition for riparian areas, one of the most comprehensive is that from the American National Research Council, which states: *"Riparian areas are ecosystems that occur along watercourses and water bodies. They are distinctly different from the surrounding lands because of unique soil and vegetation characteristics that are strongly influenced by free or unbound water in the soil. Riparian ecosystems occupy the transitional area between the terrestrial and aquatic ecosystems. Typical examples would include floodplains, streambanks, and lakeshores."* (NRC, 2002). Also, Olson et al. (2000) define riparian forests as ecosystems lying immediately upon both sides of riverbanks, including flood terraces, which interact with the river in flooding periods. Riparian vegetation can be broadly classified as wooded or grassy vegetation (Lyons et al., 2000); as soil properties and topography in riparian areas may vary significantly, riparian plant communities may correspondingly exhibit a high degree of structural and compositional diversity (Gregory et al., 1991).

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Riparian forests are among the most degraded ecosystems worldwide (Nilsson and Berggren, 2000). As they typically constitute thin strips with high edge:area ratios, biophysical changes related to forest microclimate, tree species composition and ecological dynamics may be very pronounced (Nagy et al., 2015). Some major threats to riparian ecosystems include altered hydrologic regimes due to river regulation and water extraction, vegetation clearing for agriculture and other activities, grazing by livestock, development of human settlements and infrastructure, pollution and mining (Tockner and Stanford, 2002; Naiman et al., 2005). Deforestation and expanding agricultural land use have especially caused increasing soil erosion, sediments, carbon and nutrient transport through river systems globally (Seitzinger et al., 2010). Degradation is largely responsible for reduced carbon stock in aboveground biomass, necromass, and soils in tropical riparian forests (Zelarayán et al., 2015).

Human, having been attracted to and living near streams since earliest time, can be considered a riparian creature (Meyer, 1984). Therefore, any approach to manage riparian systems must consider the anthropogenic influence on riparian zones. Their protection is acknowledged as an essential aspect of protecting a variety of ecosystem services, from water quality and availability to fostering fish spawning grounds, and conserving biodiversity; most jurisdictions have consequently established some form of regulation restricting land-use activities in these environments (Garrastazú et al., 2015). Legal protections for riparian areas and any recommendations for changes in their management must account for both the property interests in the relevant waters and lands, and the fact that most riparian areas are linear features that cross ownership/jurisdictional boundaries (NRC, 2002). McDermott et al. (2010) noted that the most appropriate approach to define the types of human activities allowed within riparian areas must consider all ecosystem services and biodiversity they provide. A key point is that the management and restoration of riparian vegetation is amenable to the scale of action of individual land managers or community groups, and their combined actions will have cumulative benefits at the landscape or catchment scale (Bennet et al., 2014). Watershed management plans, for instance, usually consider land use capability classes, determined according to the degree of susceptibility to erosion, steepness of slope, susceptibility to flooding, liability to wetness or drought, salinity, depth of soil, soil texture, structure and nutrient supply and climate (Lynn et al., 2009). However, other approaches take into account the identification and delimitation of riparian zones, to address hydrological issues in catchments' management plans (Attanasio et al., 2012a).

Natural and anthropogenic disturbing factors affect species composition and structure of the so called "gallery forests", thus endeavoring studies to quantify the extension occupied by these forest typologies, as well as their condition (Treviño et al., 2001). Riparian forests have also an important function as ecological corridors, linking disconnected lands and fostering connectivity across the landscape (Steidl et al., 2009).

Worldwide, regulations regarding riparian forest protection vary significantly. In Brazil, the concerns regarding the protection and conservation of forests along riverbanks and other kinds of water bodies are relatively new, from a historical perspective. The "protective forests" were first mentioned in the Federal Forest Law from 1934 (Brasil, 1934) and, among other objectives, they should provide protection for stream waters specially in preventing erosion due to natural agents. The economic utilization of such forests was prohibited, but incentives to keep and maintain them in private properties included land taxes exemptions. The concept of protective forests evolved to that of Areas of Permanent Preservation (APPs), which arose with the New Forest Law from 1965 (Brasil, 1965) and that were reinforced and expanded in the newest Brazilian Forest Law (Brasil, 2012), in force since 2012. Those areas consist of variable-width buffers along rivers and around water springs, lakes, wetlands, ridge lines, mountain peaks, mangroves and sandbanks as well as steep hills, which are protected by law

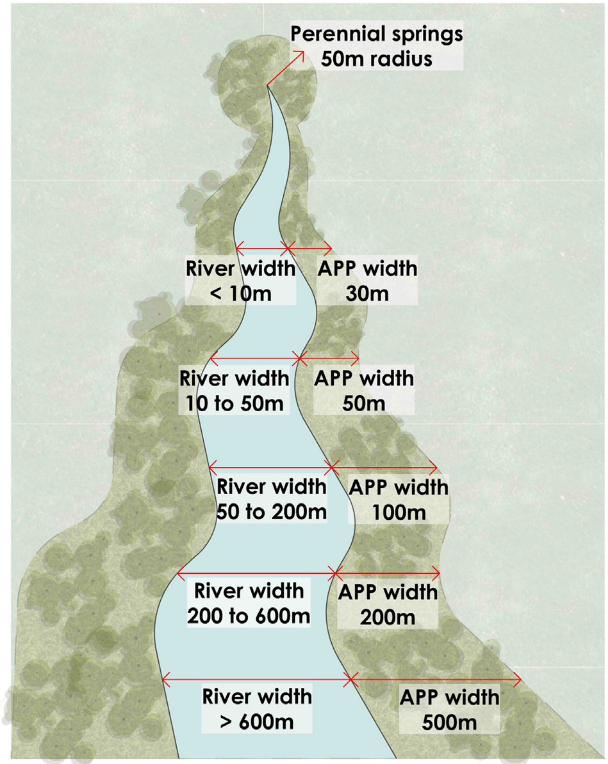

Fig. 1. Buffer widths[1] for Areas of Permanent Preservation (APPs) along rivers and water springs according to the Brazilian Forest Law (Brasil, 2012).

enforcement, no matter whether they are covered by native vegetation or not. APPs' environmental function includes preserving water resources, the landscape and the geological stability and biodiversity, as well as facilitating flora and fauna's gene flow, soil protection and ensuring the well-being of human populations (Brasil, 2012). When associated with rivers, lakes and streams they are called riparian APPs.

Broadmeadow and Nisbet (2004) point out that landscape quality is also influenced by the width of the riparian buffer. Although fixed-width buffers may locally fail conservation goals because they do not incorporate the potential importance of small scale spatial heterogeneity of riparian processes (Kuglerová et al., 2014), riparian APPs' widths in Brazil do vary within five fixed-width classes ('Minimum Permanent Preservation Areas'), depending on the river width, considered at each point (Fig. 1). Buffer widths not only apply to areas that are currently covered by native vegetation (natural grasslands, forests, etc.), but also to those that have been deforested after the year 2008, thus needing to be restored to comply with the newest Brazilian Forest Law.

Stakeholders, rural property owners and society in general still discuss the adequacy and even the necessity of establishing forest buffers along rivers. Notwithstanding, numerical and cartographic data regarding the extension and distribution of riparian forests have been already released on a national basis (EMBRAPA, 2017). Such dataset form the basis of the Brazilian Environmental Cadaster (CAR) – coordinated by the Brazilian Forest Service – and consists of declaratory inputs provided by rural properties' owners, not yet validated and subject to positional inaccuracies. The Brazilian Forest Service – working in partnership with other institutions, such as the Brazilian Agricultural Research Corporation (Embrapa), state environmental agencies, universities and research institutions – is also in charge of the

[1] According to the Brazilian Forest Law (Brasil, 2012), riparian buffers shall be measured from the edges of the regular river bed, where the water course is perennial and not from the highest water level observed during the rainy season.

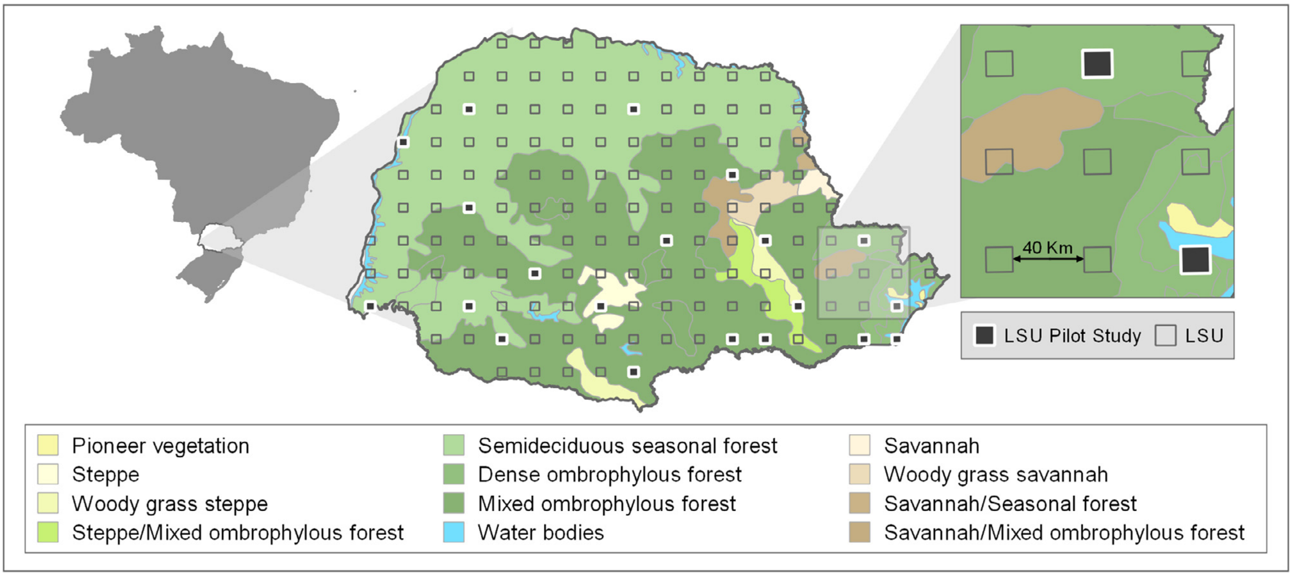

Fig. 2. Distribution of Landscape Sample Units (LSUs) on Paraná State Fitogeographical map (IBGE, 2006).

National Forest Inventory (NFI-BR).

The NFI-BR aims at producing information on forest resources to support the formulation of public policies of use, restoration and conservation (Freitas et al., 2016). Among the data sources used by the NFI-BR are the sample plots for biophysical data (like trees' diameter at breast height, species composition, phytosanitary condition, etc.), socio-environmental interviews, vegetation mapping and the Landscape Sample Units (LSUs) for landscape analysis. The Landscape Component of NFI-BR aims to analyze portions of the Brazilian territory through some quantitative indicators, such as the degree of forest fragmentation and connectivity, and the presence of riparian vegetation alongside rivers, using remote sensing techniques applied to RapidEye and Landsat-8 satellite images. The landscape analysis complements both the field plot and the socio-environmental surveys. Each LSU consists of a 100 km^2 square, distributed over a 40 × 40 km grid, whose geometric center coincides with that of the field plot (cluster). LSUs' land use/land cover (LULC) classification based on satellite imagery is an important source of information and serves as input for other types of landscape analyses. The LULC classes considered in the Brazilian NFI are: natural forest, planted forest, other wooded land (shrubs), trees outside forest (TOFs), agriculture/pasture, natural grasslands, bare soil, urban areas and water bodies.

Riparian areas associated with forested, grazed, and agricultural lands provide some of society's best opportunities for restoring habitat connectivity across the landscape (NRC, 2002). González et al. (2017) considered the need to integrate technical-ecological, socio-economic and legal aspects in riparian zones conservation plans, indicating five activities proposed by Hunter et al. (2017) to be part of a framework for an integrated conservation strategy: 1) investing in environmental education for both local people and technical staff, 2) guaranteeing qualitative and long term inventories and monitoring, 3) establishing legislation and solutions to protect riparian zones, 4) framing economic activities in riparian zones under sustainable management, and 5) planning restoration of riparian zones at multiple and hierarchical spatio-temporal scales. The NFI-BR is aligned to these actions, since many of the activities currently conducted under the scope of the NFI-BR are direct or indirectly related to those enumerated by Hunter et al. (2017).

The methodology implemented for the LSUs' analyses identifies structural riparian corridors and connectors, according to the methodology proposed by Clerici and Vogt (2013) and adapted to this work, with the main aim to spatially identify riparian restoration priorities. This is especially relevant due to the large extent of forest vegetation to be restored along rivers and water bodies, i.e. riparian areas, according to the river width defined in the Brazilian Forest Law (Brasil, 2012). To achieve this we have selected a sample of 20 LSUs from the national LSU dataset, in order to test the methodology, adopting the following steps: (i) mapping the existing riparian corridors and structural connectors between large habitat patches; (ii) calculating aggregated indices that take into account the proportion of forest cover, the degree of environmental pressure and the presence of protection schemes (Areas of Permanent Preservation, Conservation Units); (iii) ranking corridor regions based on these indices, and; (iv) detecting critical riparian regions for conservation priorities. It must be pointed out, though, that all analyses refer to the existing corridors, consisting of forest vegetation types, without considering those areas which are not in compliance with the law, i.e., rural properties whose river buffers are not covered by native vegetation.

2. Materials and methods

2.1. Study area and ancillary data

The study area consists of a sample subset of 20 LSUs selected from the 138 LSUs assigned for the Paraná State, in Southern Brazil. The selection has been applied in such a way that the selected LSUs are representative of the variation of all phytogeographic regions present in the State (Fig. 2). The LSUs are equidistantly distributed throughout the Brazilian territory on a regular 40 × 40 km grid and each sampling unit covers a total area of 100 km^2 (10 × 10 km). Therefore, this study comprised a total area of 2000 km^2.

Land use/land cover (LULC) mapping was performed using an object-based approach (OBIA) based on RapidEye 5 m spatial resolution imagery (2013 coverage), along with ancillary data as the Global Forest Cover data (Hansen et al., 2013), Landsat-8 OLI Top of Atmosphere (TOA) reflectance imagery, as well as 32-day vegetation index composites along the year (Luz et al., 2015). LSUs' perennial streams were extracted from Paraná State 1:50,000 river network layer, developed by different public institutions (Souza et al., 2011).

We have applied the methodology developed by Clerici and Vogt

(2013), introducing slight changes mostly related to the approach adopted for determining riparian zone boundaries. Those authors compiled a riparian vegetation map covering the EU27 from multi-source GIS and remote sensing data (Clerici et al., 2011, 2013). From this dataset, the European riparian areas were mapped at a spatial scale of 25 m grid squares, combining hydrological and geomorphological data, and land use information, including forest cover on a continuous scale of riparian-area occurrence probability. In Brazil, there is no comprehensive map of riparian zones for the country, and the delineation of their boundaries is restricted to experimental studies in specific sites (e.g. Zakia et al., 2006; Attanasio et al., 2012b; Barros et al., 2015). Thus, in this work we have delineated a fixed distance of 500 m at each side of river edges in order to delimit a riparian zone – such as proposed by Ivits et al. (2009). This distance coincides with the maximum range required for APPs by the Forest Law for rivers 600 m wide or wider, in areas that are covered by native vegetation (natural grasslands, forests, etc) and for those that have been deforested after the year 2008. All analyses have been carried out within this 500 m-buffer mask.

2.2. Mapping structural corridors and connectors

Corridors can be viewed as regions of the landscape that facilitate the flow or movement of individuals, genes and ecological processes (Chetkiewicz et al., 2006), thus being responsible for both functional and structural aspects of the connectivity between habitats. When analyzing the structural connectivity, emphasis is given to habitat amount, spatial configuration and condition across multiple scales (Andersson and Bodin, 2009).

In our study, the structural connectivity analysis was performed applying the Morphological Spatial Pattern Analysis – MSPA (Soille and Vogt, 2009), a segmentation technique implemented in the free software collection GuidosToolbox (Vogt and Riitters, 2017). MSPA was performed on a raster grid where the foreground pixels correspond to the forest mask (habitat) within the riparian zone, extracted from NFI-BR LULC map (see section 2.1). When the foreground pixels represent the forest mask, it is important to determine to which extent anthropogenic edges can directly (e.g., canopy openness) or indirectly (e.g., patterns of tree recruitment) affect ecological processes in forest habitats (Cayuela et al., 2009). The intensity of edge effects can be measured as the distance *d* in which changes in abiotic and biotic factors are observed, although it is unrealistic to expect a monotonic variation in all edge effects (Murcia, 1995). Moreover, the definition of the edge width depends heavily on the effect being studied. Studies on the depth-of-edge influence in subtropical forests show a wide range of values depending on the variables related to distance from edge, e.g. 50 m (Moro et al., 2015), 16 to 137 m (Chen et al., 1992); 20 to 35 m (Malchow et al., 2006); 35 m (Rodrigues, 1998) and 30 m (Magrach et al., 2013; Pedroso-de-Moraes et al., 2015; Tejera et al., 2012; Wicklein et al., 2012; Ziter et al., 2014). In this study an edge distance of 30 m was adopted, being recognised as a representative average distance.

MSPA segments the foreground mask into seven mutually exclusive pattern categories (Fig. 3): *Core* – inner foreground pixels beyond the user-defined distance $d = 30$ m from foreground-background boundary; *Edge* – foreground pixels between *core* and external background; *Perforation* – foreground pixels between *core* and internal background; *Bridge* – connecting pathway of foreground pixels between at least two disjoint *core* areas; *Loop* – connecting pathway of foreground pixels originating and returning to the same *core* area; *Islet* – foreground patch too small to contain *core*; *Branch* – foreground pathway connected at one end to *Edge*, *Perforation*, *Bridge*, or *Loop*.

In analogy with network theory, only the classes *Core* and *Bridge* within the 500 m-buffer mask were selected to represent those portions

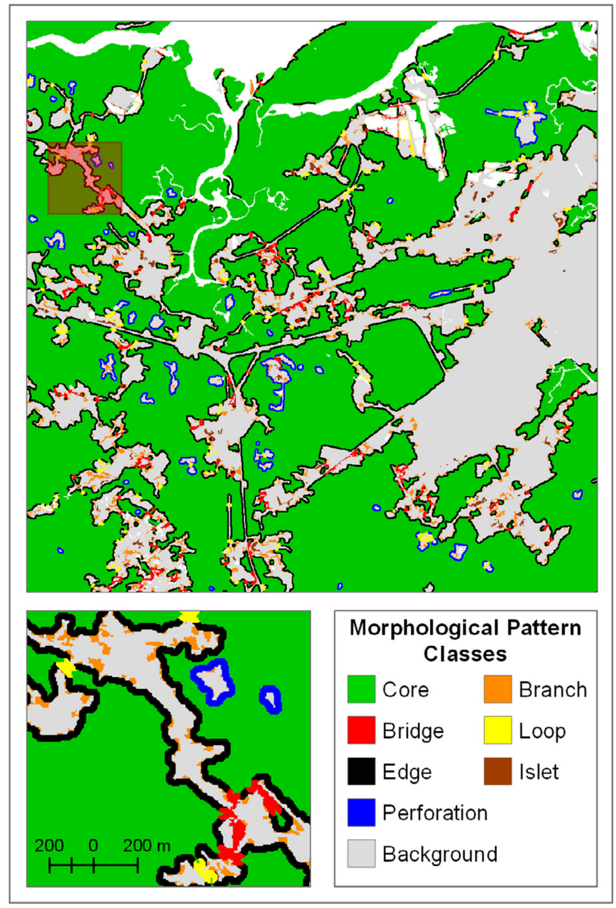

Fig. 3. Example of MSPA output. The zoom to the left side of the image shows classes Bridge, Branch, Edge, Core, Loop, Perforation and Islet in detail.

of the landscape that can function as corridors and connectors in riparian zones (Fig. 4).

2.3. Aggregated indices

Aggregated indices, as defined by Clerici and Vogt (2013), were calculated for assessing riparian zones within the analyses, carried out at the landscape scale in the Brazilian NFI. The indices are based on the structural connectivity of these environments as vegetation corridors, the degree of human pressure acting on them and the protection schemes defined by the Brazilian forest legislation. The indices are calculated, and finally turned into scores, to derive a ranking that allows the identification of priority areas for riparian conservation and landscape restoration.

A 100 × 100 m polygon grid was created over the entire area of each LSU, and the indices were calculated for each *c* cell of 1 ha that contained any surface covered by the *Core* and *Bridge* classes within the riparian zone mask. The first step to calculate the indices was to select the grid cells that intersected the polygons of *Bridge* and *Core* classes (Fig. 4), denominated *c* cells. The Structural Corridors Index (SC_c) reveals the proportion of the area occupied by the classes *Bridge* and *Core* in each *c* cell of 1 ha. Regions with dense drainage systems and extensive natural areas present a high SC_c. The index was calculated for every *c* cell by applying Eq. (1):

$$SC_c = \frac{B_c}{S} \tag{1}$$

where:

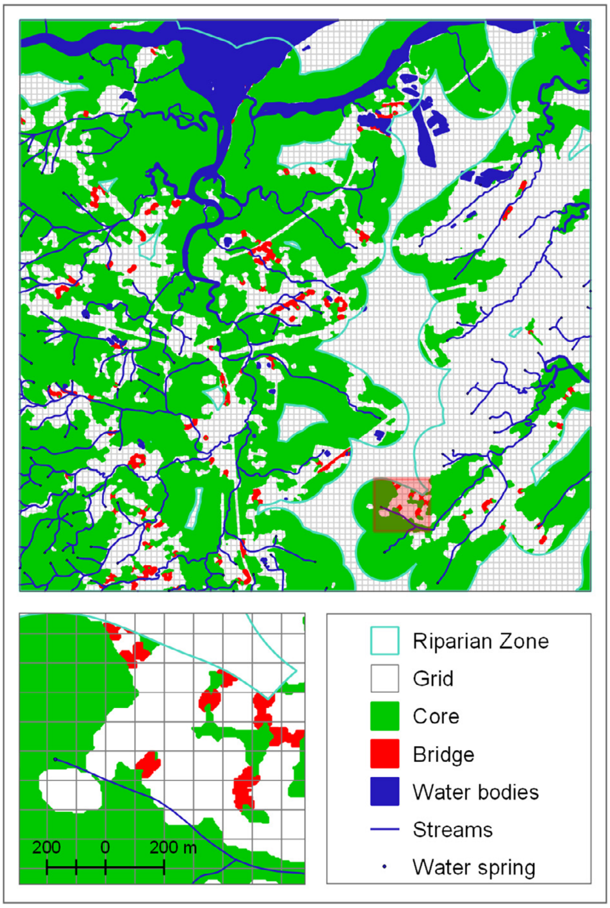

Fig. 4. Riparian zones established as 500-m-wide buffers along riverbanks for one LSU from the study area and MSPA classes *Bridge* and *Core* within the riparian zone.

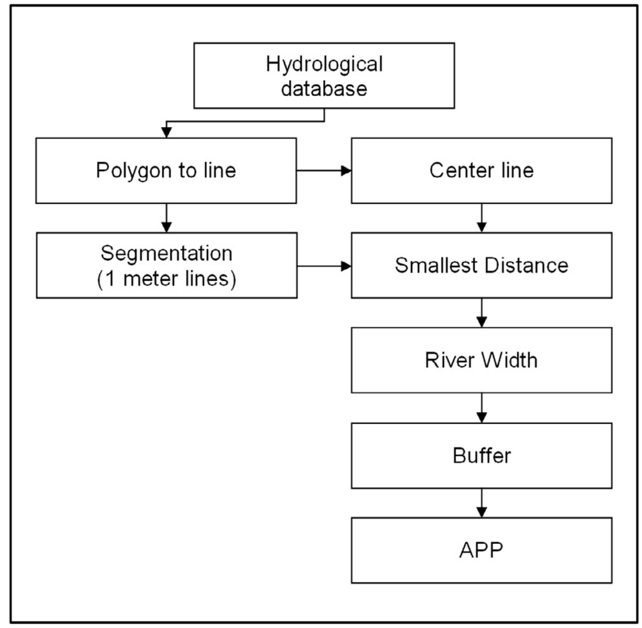

Fig. 5. Flow-chart representing the methodology applied to determine the APPs.

B_c = surface occupied by the classes *Bridge* and *Core* (ha) in the cell c; $S = c$ cell area (1 ha).

The Structural Corridors under Pressure Index (CP_c) is an integration of the SC_c and brings information on the proportion of non-natural areas (artificial and agricultural) in each c cell. Its application may lead to the identification of areas where there is significant presence of structural riparian corridors coexisting with anthropogenic pressure. First we calculated the proportion of the surface occupied by non-natural (artificial and agricultural) land use classes in each c cell (A_C) which could be obtained by overlaying the derived land use-land cover map over the c cells. Then the index was calculated as shown in Eq. (2):

$$CP_c = SC_c * A_c \quad (2)$$

The Structural Corridors under Pressure Protection Index (UCP_c) is a further integration of the CP_c index and brings information on the proportion of areas under some protection scheme. For the LSUs, the protected riparian buffer zones are represented by different buffer widths along rivers, that correspond to limits set in the Brazilian Forest Law for Areas of Permanent Preservation (Brasil, 2012; see Fig. 1). The buffers' or APPs' widths were determined applying the methodology described by Jesus and Souza (2016), using data from the hydrological database of the Paraná State (Souza et al., 2011) corresponding to our pilot areas, using GIS software. Given the scale of the hydrological database, a 30-m buffer was applied for rivers featured by lines. As proposed by Jesus and Souza (2016), rivers represented by polygons were converted to polylines, resulting in a vector file corresponding to the river margins to be analyzed. The lines were then segmented, meter by meter. The lines were also used to generate a vector layer of the river central line. These line features were used to calculate the distances between the segments that composed the river margins and the central line of the river, using a neighborhood function that calculates the smallest distance between two features. As such, it was possible to calculate the exact width of the river to each 1 m segment along its margins. To calculate the absolute river width values, a new field was inserted in the table of segment attributes that doubled the results of the neighborhood function. Having determined the river width data, the segments were separated in files according to river width categories as determined by law (Brasil, 2012), i.e.: up to 10 m; from 10 to 50 m; from 50 to 200 m; from 200 to 600 m; and larger than 600 m. A buffer was generated for each of these groups according to the corresponding legal APP widths: 30 m; 50 m; 100 m; 200 m and; 500 m respectively (Fig. 5). We also took into account the existence of integral protection Conservation Units established under the National System of Conservation Units (SNUC) within the LSUs. Although the protection provided by river buffer widths in these environments substantially exceeds those disposed in law, thus reaching the whole maximum riparian zone width (500 m), many of them still lack management plans and face land tenure problems (Drummond et al., 2009), which threatens their effectiveness in protecting the riparian ecosystems existing within their boundaries.

The proportion of protected riparian zones with respect to their total amount in each 1-ha-cell (P_c) was calculated by overlapping the respective buffer on the selected 100 × 100 m grid cells, where classes *Bridge* and *Core* occurred. The UCP index was calculated using the formula (Eq. (3)):

$$UCP_c = \frac{CP_c}{P_c} \quad (3)$$

In cells with no protection at all, to avoid division by zero, we have set the P_c value to 10^{-6}. If there are few protected areas (denominator), the index value will increase. High UCP_c values correspond to a high ranking assigned to the cell c, indicating significant presence of structural riparian corridors under anthropogenic pressure and with little or no protection. Cells with high UCP_c scores represent potential priority areas for conservation and management of riparian corridors (Clerici

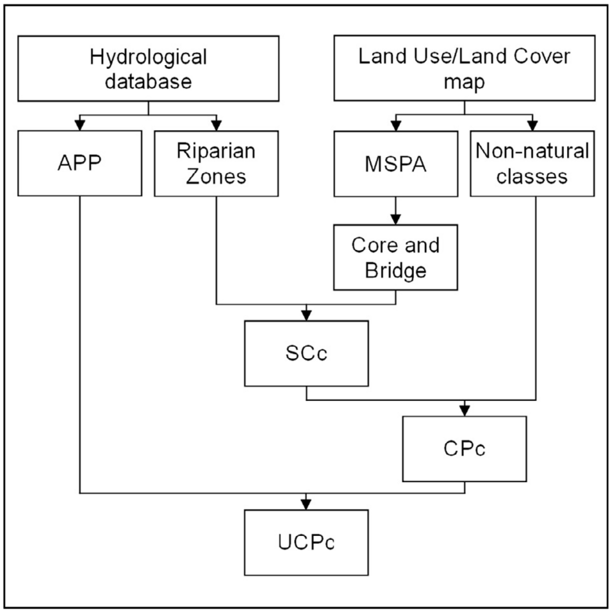

Fig. 6. Flow-chart representing the sequential operations in the riparian structural corridors assessment.

and Vogt, 2013).

A flow-chart representing the sequence of methodological operations is shown in Fig. 6.

2.4. Indices standardization and ranking of corridor regions

To facilitate comparisons between different scenarios in one particular LSU or between different LSUs, the results were mapped applying a min-max normalization of the indices SC_c, CP_c and UCP_c (separately) computed for each c cell, generating scores ranging from 0 to 1 (Eq. (4)).

$$I_{res_c} = \frac{I_c - I_{min}}{I_{max} - I_{min}} \tag{4}$$

where I_{res_c} = re-scaled value for index I_c (SC_{res_c}, CP_{res_c} and UCP_{res_c}, separately) in cell c; I_c = index I_c (SC_c, CP_c and UCP_c, separately) in cell c; I_{max} = maximum value for index I_c in all LSUs from the dataset; I_{min} = minimum value for index I_c in all LSUs from the dataset.

In order to obtain a representation for the Paraná State, we have separately calculated the mean statistics for each index (SC_{res_c}, CP_{res_c} and UCP_{res_c}) over all the cells within the riparian zones for each LSU considered. A new min-max normalization was then applied and the resulting maps showed the summarized indices for the 20 pilot LSUs. For these representations, we have adopted five value classes using the natural breaks methods (Jenks, 1967) where the classes are based on natural groupings inherent in the data. Break points are identified by picking the class breaks that best group similar values and maximize the variances between classes.

3. Results and discussion

Results showed that higher SC_c values occur in regions where we find a combination of a dense river network and an extensive natural landscape (constituted by forest-type vegetation). In these cases, the vast natural and semi-natural conditions allow the formation of larger and denser riparian zone networks, increasing consequently the probability to find physical corridor structures (Clerici and Vogt, 2013). We represented higher values – which denotes the presence of structural corridors – by green tones, while lower values were represented by red tones (Figs. 7 and 8).

For the pilot subset considered in this study, the three LSUs with highest values were LSU 1183 (Fig. 7(a)), 1151 and 1149, displayed in green tones in Fig. 8. A large presence of riparian structural corridors is located in LSUs where forest cover still prevails, either due to the existence of traditional farm systems or because they are located in legally protected landscapes. The protection schemes may refer to the existence of state conservation units where sustainable use is permitted (LSUs 1151, 1149 and 1214 within the “Guaratuba State Environmental Protection Area”), or to federal integral protection conservation units, as LSU 1183, located inside the “Iguaçu National Park”. This suggests that those environmental protection systems do favor the protection and conservation of structural corridors. Nevertheless, LSUs 1076, 1503 and 1196 also presented high values for Index SC_c (Fig. 8), with values corresponding to the second-best class, and are not under the protection of any conservation unit.

Regions where the riparian zone is composed by small and very fragmented natural areas within a predominantly agricultural or urban matrix, showed low values for Index SC_c, like LSU 1707 (Fig. 7(b)), which presented the lowest value for this index, followed by LSUs 1127, 1188, 1349 and 1343 (Fig. 8). However, LSU 1580, even including the “Ilha Grande National Park” – an integral protection federal conservation unit – and the “Ilhas e Várzeas do Rio Paraná State Environmental Protection Area” – a sustainable use conservation area – showed a low value for this index. This result may be related to the fact that the landscape in this region is constituted mainly by grasslands, a LULC class that belongs neither to the core nor to the bridge category in the MSPA analysis, as only forest typologies were considered in our study.

The Structural Corridors under Pressure Index (CP_c) allowed the identification of areas where a significant extension of structural corridors coexist with anthropogenic landscapes. In this case, regions with high CP_c values denote the presence of structural corridors associated with landscapes where agriculture or other artificial LULC types predominate. In our maps, these index values were displayed using red tones, which represent the marked anthropogenic influence on the existing structural corridors, while lower values were represented by green tones, associated to regions with less anthropogenic pressure (Figs. 9 and 10).

The LSU with the highest value for the CP_c Index was LSU 1707, followed by LSU 1406 (Fig. 9(b)), where the structural corridors were subjected to a more intense anthropogenic influence in comparison to other LSUs. Unlike LSU 1707, the LSU 1406 did not stand out in relation to the presence or lacking of structural corridors, represented by the SC_c Index. However, a significant proportion of the existing corridors intersects or is surrounded by non-natural LULC types.

On the other hand, LSUs with riparian zones less influenced by human activities presented low values for this Index, like, for instance, LSU 1580 (Fig. 9(a)). This particular LSU showed low values for the SC_c Index, what denotes the presence of few structural corridors, but presented low values for the CP_c Index as well, what reflects a weak anthropogenic influence. This is coherent with the specific characteristics of this LSU, located within a conservation unit – what explains the less intense or non-existing anthropogenic influence – as well as its predominant LULC type, represented by the class “grassland”, which does not belong to forest core or bridge categories. Other three LSUs (1151, 1183 and 1214), also within conservation units, showed the lowest values for the CP_c Index (Fig. 10).

High values of UCP_c Index correspond to a high ranking assigned to each c cell within the LSU, representing large presence of riparian structural corridors, subjected to environmental pressure and with low degree of protection or no protection at all, here represented by the law enforcement relative to Areas of Permanent Protection (APPs). In our resulting maps, this situation is displayed by cells in red tones (Figs. 11

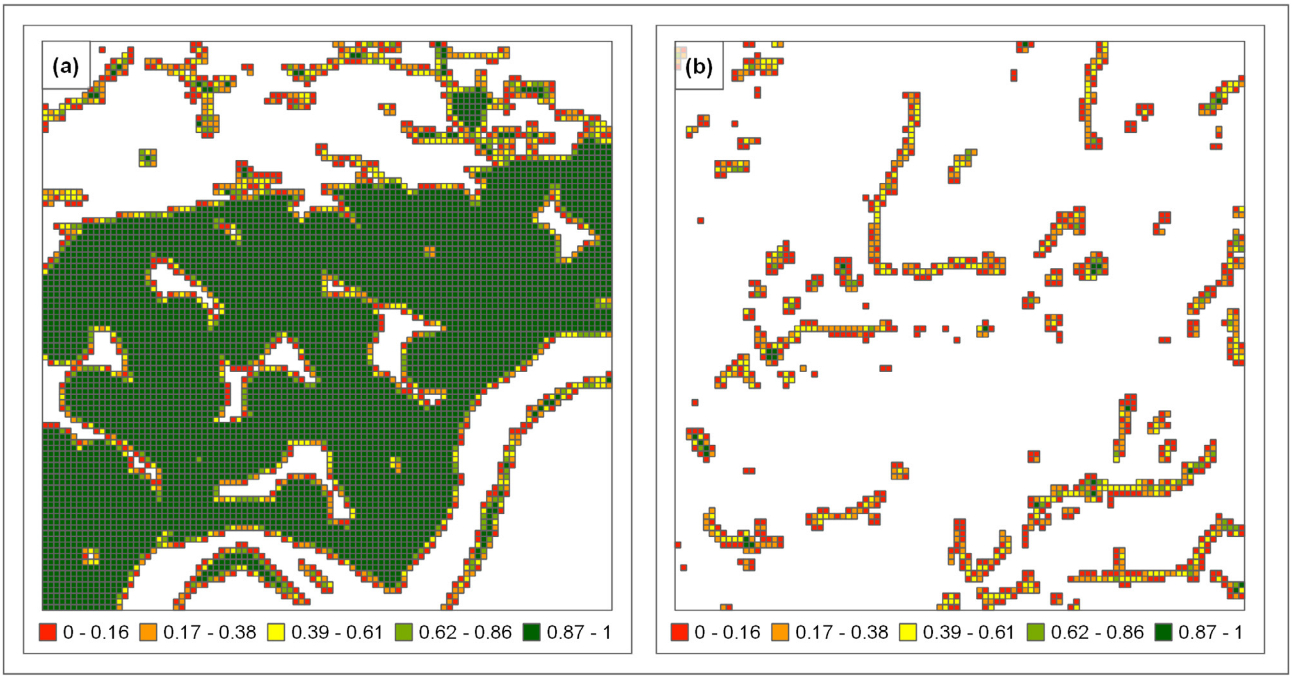

Fig. 7. SC_c Indices for individual cells in (a) LSU 1183 and (b) LSU 1707.

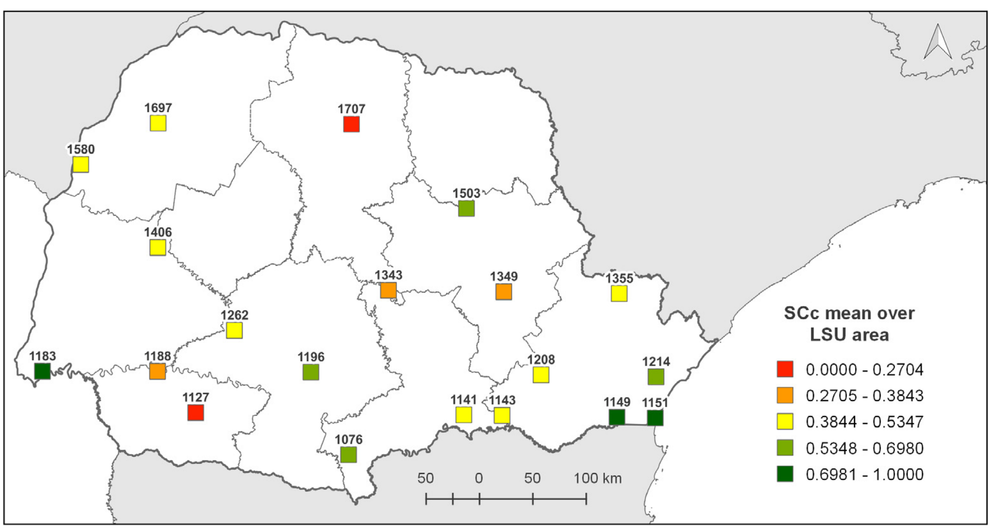

Fig. 8. Index SC_c per LSU (mean of all cells within each pilot LSU).

and 12), representing potential priority regions with respect to conservation and management of riparian corridors. The UCP_c index is strongly affected when river widths are larger than 10 m, which increases APPs' surface, thus reducing the value of the UCP_c Index. This is due to the rules adopted for determining Areas of Permanent Preservation (see Fig. 1) under the New Forest Law (Brasil, 2012).

The Landscape Sample Units which presented the highest values for this index were LSU 1349 (Fig. 11(b)), 1262 e 1143, although less than 15% of their areas benefit from the legal protection schemes considered in this study (Table 1). In the same table we can observe that in almost half of the pilot LSUs the effective area covered by forest formations in APPs lies close to the extension prescribed by law. One-fourth of them presents half the extension of the expected forest-type vegetation along rivers and for another one-fourth the extension of forest-covered APPs is much smaller than the extension determined by law.

As expected, cells with low values for the UCP_c index correspond to regions with structural corridors and large areas under legal protection (APPs). This was observed for LSUs 1343 (Fig. 11(a)), 1183 e 1151, which presented a dense river network thus contributing to an increasing area considered as APP. In the case of LSUs 1183, 1151, 1580 and 1149, notwithstanding the denser river network, they are partially enclosed in full protection conservation units, which expands the protection schemes to which they are subjected.[2]

Landscape Sample Unit 1343, for instance, presented the best mean for the UCP_c index and shows more than 40% of its area under legal protection schemes related to river buffers. However, the effective area covered by natural forest formations is just slightly greater than 22% (Table 1).

[2] Fixed or mandatory riparian buffers do not apply in Conservation Units as they are constituted mostly by natural environments, with no anthropogenic land use along rivers. Therefore, in those areas, the APPs are not dependable on the river width and can be considered as the whole riparian zone (500 m buffer).

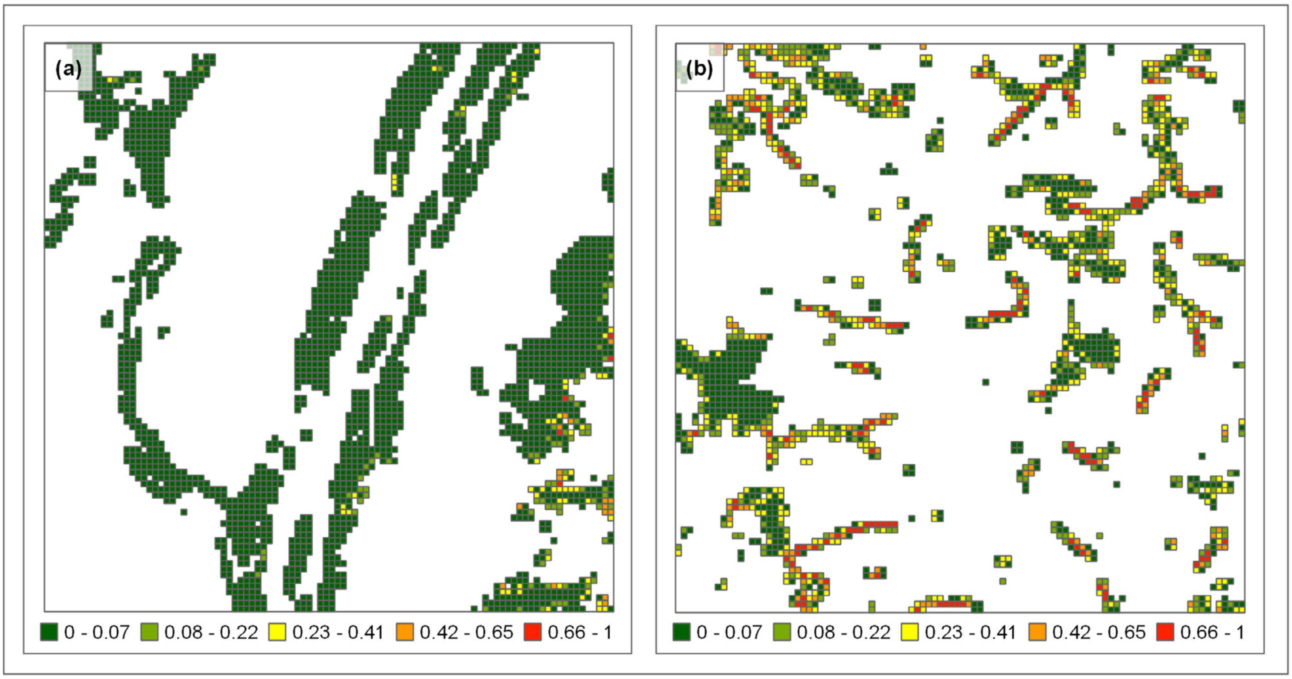

Fig. 9. CP_c Indices for individual cells in (a) LSU 1580 and (b) LSU 1406.

Generally speaking, the higher the values for indices CP_c and UCP_c, the higher the chance of critical situations from a conservation perspective (Clerici and Vogt, 2013), because these indices are indicators of anthropogenic pressure and a lack of protection schemes. In our study, the three LSUs with the highest mean values for both indices were, respectively, LSU 1349 (Fig. 11(b)), 1262 e 1143. As also stated by González et al. (2017), these types of measures provide integrative techniques to valorize inventory data and communicate them more easily. As can be seen from the maps presenting results for the Structural Corridors Under Pressure Protection Index (UCPc) (Figs. 11 and 12), LSUs 1349 and 1262 are potential priorities regarding riparian zones restoration, together with LSU 1143. Those are not the least forested LSU nor the ones bearing more pressure, but are considered a priority instead because they congregate those aspects with the lack of protection schemes.

It can be noticed that LSU 1349 can be considered a priority region in the state of Paraná amongst those analyzed, and priority areas for restoration within the LSU 1349 are indicated by red cells, highest UCPc values. This is a type of information readily useable by a politician or a government technician responsible for law development or public policy for riparian zones conservation as well as financial resources allocation. The conversion of information (land use/land cover maps, and hydrography data) into colorful and, most important, meaningful maps, ready to be used by government and general public and fully understood, conveying important information on health, quantity and quality of natural resources and especially forests, are the main goal of the NFI-BR.

4. Conclusions

The methodology presented in this article, adapted from the one proposed by Clerici and Vogt (2013), uses information from the NFI-BR

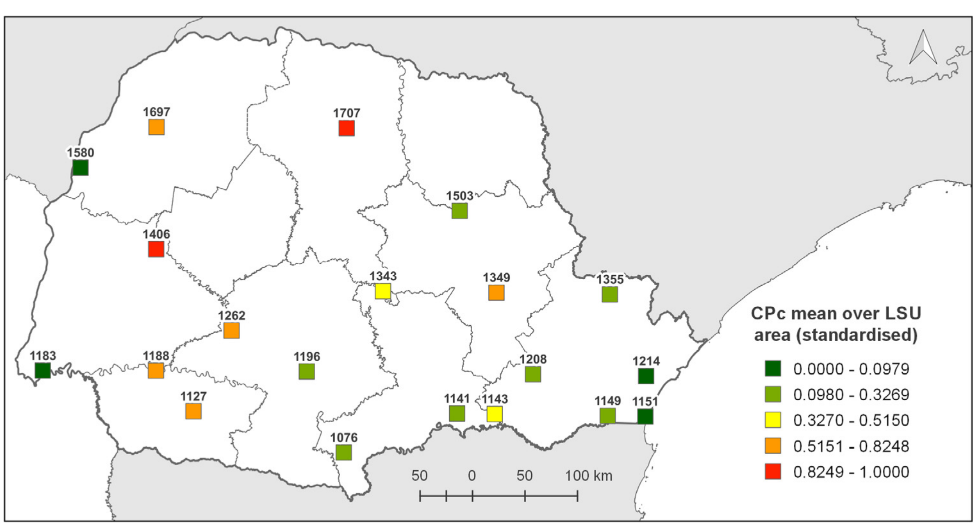

Fig. 10. Index CP_c per LSU (standardized mean of all cells within each pilot LSU).

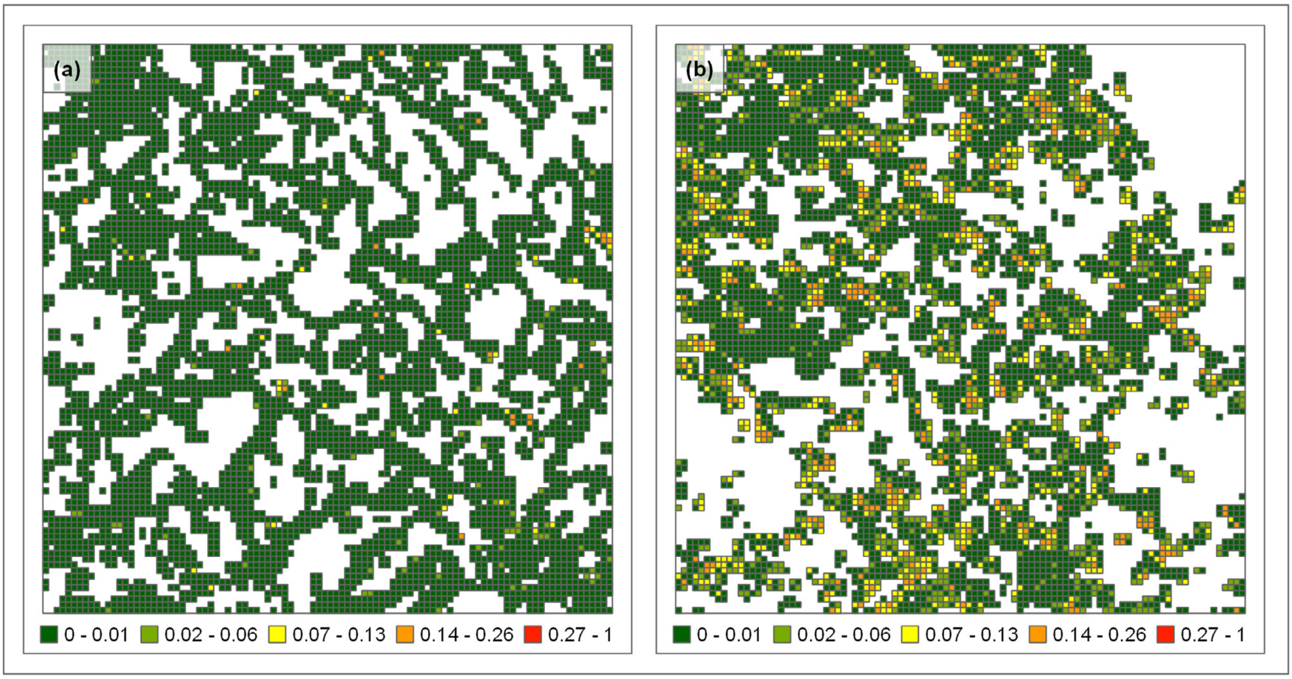

Fig. 11. UCP_c Indices for individual cells in (a) LSU 1343 and (b) LSU 1349.

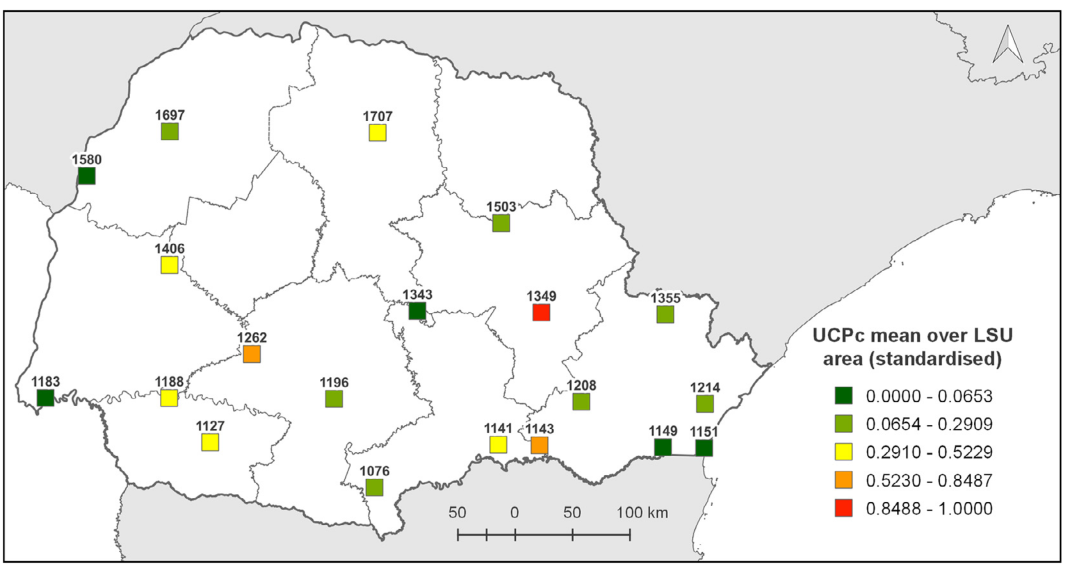

Fig. 12. Index UCP_c per LSU (standardized mean of all cells within each pilot LSU).

LULC mapping to identify structural riparian corridors and its connectors and to rank them with reference to conservation and restoration priority. Based on the proportion of forest cover, the degree of environmental pressure and the presence of protection schemes, ranking corridor regions allows a first detection of critical riparian zone areas for restoration and conservation. The entire analysis was based on free software, thus allowing its replication in other studies and situations.

Establishing evaluation criteria for conservation facilitates the design of landscape management plans, subsidizes public policy development and helps on the enforcement of restrictive legislation (Ayram et al., 2016). A task that seems simple when good spatial resolution land use/land cover data is available, selecting priority areas for restoration turns out to be far more complex when other aspects impacting on and interacting with riparian zones are considered, such as degree of anthropogenic pressure and presence of protection schemes. It may be relatively simple to look at Federal State LULC maps and identify areas where natural ecosystems are more degraded and land use is more intense, thus making riparian zones restoration necessary. The weighting of many aspects is a difficult task but can be performed with the aid of integrated landscape indices. Another important aspect of the proposed methodology is the possibility to identify and prioritize areas at different spatial scales, further aggregating the indices for LSU or larger political regions, such as micro and meso-regions of federal states. It makes possible to know restoration needs in a river within a landscape, and also in what part of the state the connectivity of riparian zones is more threatened.

Apart from riparian zones, as previously mentioned, other aspects of the occurrence of forest resources and its interaction with other LULC

Table 1
SCc, CPc, UCPc Indices, percentage of LSU area contemplated by law enforcement relative to Areas of Permanent Preservation and percentage of this area effectively covered by forest formations per LSU.

LSU	SC_c	CP_c	UCP_c	APP_{legal} (%)	APP_{real} (%)
1343	0.37	0.51	0.00	41.89	22.44
1183	0.85	0.03	0.01	50.06	49.27
1151	0.82	0.00	0.02	30.69	28.39
1580	0.51	0.00	0.03	30.45	13.69
1149	0.80	0.10	0.07	23.59	20.05
1355	0.46	0.27	0.14	23.17	14.53
1214	0.70	0.08	0.17	16.24	12.82
1196	0.57	0.25	0.24	13.55	6.35
1697	0.43	0.77	0.25	9.62	2.97
1076	0.64	0.33	0.26	22.20	15.02
1208	0.52	0.28	0.27	18.00	10.32
1503	0.60	0.29	0.29	16.17	12.50
1141	0.52	0.25	0.37	12.99	6.55
1406	0.38	0.82	0.37	9.56	4.29
1188	0.33	0.67	0.45	26.01	7.25
1707	0.27	1.00	0.49	4.29	2.47
1127	0.27	0.74	0.52	17.92	5.65
1143	0.53	0.48	0.79	10.24	8.44
1262	0.49	0.73	0.85	13.80	9.70
1349	0.37	0.70	1.00	13.39	5.28

types are analyzed in the Landscape Component of the NFI-BR. Integration of the Riparian Corridors Analysis with connectivity, for example, is foreseen in a few ways. Connectivity analysis is also carried out for the entire LSU using different parameters and tools, showing how the entire landscape is connected and which ones are the most important connections to be preserved within each LSU thus expanding the prioritization of landscape corridors restoration outside the riparian zones. Habitat Similarity and Fragmentation are to be integrated in the diagnosis phase, together with other environmental and socio-economic data in a holistic view.

Future steps will also include an integrated analysis with the Brazilian Environmental Rural Cadaster (CAR), whose data is entered in an online GIS-like system by the property owner, responsible for the correct declaration of Legal Reserve and Permanent Preservation Areas. As the declaration period is not yet complete, not all covered LSUs are available. Nonetheless, data can already be accessed online in a database that still lacks validation regarding positional accuracy. It is worth noting that the CAR database includes also information on APPs whose use is anthropogenic – the so called "consolidated APPs" – subject to different restoration rules. The integrated indices showed in our study could also be applied to these especial situations in order to provide a more realistic snapshot from the riparian forest zones in Brazil.

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